ENHANCED CMTS FOR RELIABILITY, AVAILABILITY, AND SERVICEABILITY

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Continuation-in-Part of the following patent applications, the disclosures of which are herein incorporated by reference for all purposes:

U.S. Patent Application Ser. No. 09/715,992, entitled "METHODS AND APPARATUS FOR TRANSMISSION OF ANALOG CHANNELS OVER DIGITAL PACKET-BASED NETWORKS," Liva et al., filed November 16, 2000; and

U.S. Patent Application Ser. No. 09/800,397, entitled "TRANSCEIVER CHANNEL BANK WITH REDUCED CONNECTOR DENSITY," Alok Sharma, filed March 5, 2001, which in turn claims priority to U.S. Provisional Patent Application Ser. No. 60/187,194, entitled "FREQUENCY AGILE DIGITAL TRANSCEIVER BANKS HAVING NON-UNIFORM CHANNEL WIDTH AND REDUCED CONNECTOR DENSITY," Alok Sharma, filed March 6, 2000;

this application also claims priority to the following patent application, the disclosure of which is incorporated by reference for all purposes:

U.S. Provisional Patent Application Ser. No. 60/294,656, entitled "I/O CARD," Wingfield et al., filed May 30, 2001.

This application also incorporates by reference the following patent applications: Docket No. PBC.2000.110, entitled "ENHANCED FIBER NODES WITH CMTS

CAPABILITY," Liva et al., filed October 24, 2001; and U.S. Patent Application Ser. No. 09/974,030, entitled "MULTIPLE INPUT, MULTIPLE OUTPUT CHANNEL, DIGITAL RECEIVER TUNER," Fabien Buda, filed October 10, 2001.

BACKGROUND

[0002] Cable Modem Termination Systems (CMTSs) play important roles in cable networks, delivering integrated data, telephony and video to subscribers over regional and last mile Hybrid Fiber-Coax (HFC) networks.

[0003] CMTS Reliability, Availability, and Serviceability (RAS) is a concern for network vendors, as failure or performance degradation of key components can entail both downtime for network subscribers, as well as costly service time to make repairs. The large number of cables that connect to a typical Line Card – the CMTS component with primary processing functionality – to provide upstream and downstream channels makes for a lengthy recabling process when the card needs to be serviced. Disconnecting and reconnecting so many cables is also prone to error, further increasing the time associated with CMTS maintenance.

[0004] Another costly maintenance area is the adjustment of upstream and downstream channel assignments, such as done for noise abatement or when configuring a replacement or backup Line Card. Previously, this has been manually performed at the physical site of the CMTS, placing further demands on service technicians to make time-consuming and error-prone adjustments to a CMTS.

SUMMARY

[0005] The present invention teaches CMTS implementations that provide enhanced Reliability, Availability, and Serviceability. In an illustrative embodiment, the CMTS is partitioned into Line Cards, I/O Cards, and a midplane, and organized and operated in a manner that reduces maintenance errors, minimizes downtime as perceived by the subscriber, and shortens and simplifies maintenance.

[0006] Each I/O Card provides a cabling interface for coupling an assigned Line Card to other portions of a Hybrid-Fiber-Coax Network. The configuration of the network cabling for the I/O Card is custom to each Line Card. Carrying out the network cabling configuration is thus a time consuming and error prone manual operation requiring a trained technician. In accordance with the invention, a standardized interface is defined to couple a plurality of RF signals between each Line Card and a corresponding I/O Card, via the midplane. The standardized interface isolates the Line Card from the custom network-cabling configuration that the I/O Card sees, and permits the Line Card to be removed for servicing and its replacement reinserted, without revisiting the undesirable manipulation of the cabling of the corresponding I/O Card.

[0007] To enable RF signals to be passed between the Line Card and I/O Card, via the midplane, the inventors discovered a connector-based transmission approach that has signal integrity and impedance properties normally associated with coaxial cables and coaxial connectors, while avoiding these expensive components. Specifically, a multi-pin collinear connector-cascade (Line Card jack, midplane double-plug, and I/O Card jack) is employed, having in cross-section an array of conductors, and wherein each RF signal in the array is surrounded by protective RF grounds.

[0008] In a preferred embodiment, a rectangular-multi-pin connector of the compact-PCI (cPCI) connector standard is chosen, and 8 pins connected to RF ground surround each RF signal on the rank, file, and diagonals. The cPCI connector chosen has sufficient numbers of rows and columns of pins, that a plurality of RF signals may be coupled via the same connector. This permits each Line Card to be removed or inserted in a single action, without attention to individual RF interconnects, while meeting all system RF requirements.

[0009] The inventors discovered that a cPCI connector-cascade configured as described presents a negligible impedance discontinuity when used to pass RF signals as part of an industry standard 75-ohm transmission line. The inventors further discovered that all signal integrity and other system RF requirements (including cross-talk, susceptibility, and emissions requirements) of the CMTS are achievable using the cPCI connector-cascade to pass a plurality of RF signals between the Line Card and the I/O Card.

[0010] The I/O Cards preferably include a distributed backup bus that permits one of the Line Cards in the CMTS to serve as a designated backup. The backup bus enables assignment of the designated backup Line Card to the I/O Card associated with a failing Line Card, without requiring recabling of any I/O Card.

[0011] The Line Cards preferably use a signal processing architecture that permits dynamically programmable channel assignments. This eliminates the need for technician-performed field configuration of each Line Card for its associated upstream and downstream channel assignments. These assignments may be re-programmed at any time locally, remotely, or automatically, for a variety of purposes including dynamic noise abatement and maintenance.

[0012] In conjunction with the ability to dynamically program channel assignments, the backup bus facilitates rapid and fully automated failover. Upon failure of a Line Card, monitoring circuitry detects the fault, configures the designated backup Line Card to assume the channel assignments of the failed Line Card, and redirects the information streams of the I/O Card to the designated backup Line Card. The automated failover does not require involvement of maintenance personnel and minimizes the service downtime experienced by the subscriber.

[0013] The Line Cards are preferably further partitioned into easily replaceable sections, including a detachable module for optional IF-to-RF functionality and a detachable daughter card for the signal processing functions. Two different implementations are taught for connecting the Line Card to the IF-to-RF module, one using Line Card and module complementary pairs of push-on-mating (including slide-on and snap-on, and preferably self-aligning) coaxial-connectors, and another providing the Line Card to module interconnect through coaxial cables.

NOMENCLATURE

[0014] In the communications industry certain common terms find repeated application at different levels of the design hierarchy and otherwise may be used with varying scope. As a result, it is possible that terms used in this application have multiple context dependent meanings. Particular attention is required with regard to the terms demodulator, receiver, tuner, and front-end. Those skilled in the art will always be able to readily ascertain the correct meaning from careful study of the text and accompanying drawings.

[0015] Note that both analog RF and packet data transmissions may be carried over either electrical or optical paths. Furthermore, note that analog RF transmissions include digital modulation methods, including the DOCSIS compatible techniques for communicating between the CMTS and subscriber cable modems.

Brief Description of Drawings

[0016] Fig. 1(A) provides an abstract drawing of an illustrative enhanced Fiber Node (eFN, **5000**) in accordance with the invention. Fig. 1(B) provides additional detail of one of the Line Cards **100**, of Fig. 1(A).

[0017] Fig. 2(A) and Fig. 2(B) detail different embodiments of the Combine and Split Function (CSF, **5400**), of Fig. 1(A).

[0018] Fig. 3 illustrates a regional Hybrid Fiber-Coax Network (HFCN, 3000) incorporating two types of Fiber Nodes (FN1, **3400** and FN2, **3500**), and wherein the eFN **5000** of Fig.1 finds multiple applications.

[0019] Fig. 4 provides an abstract drawing detailing prior-art Customer Premises Equipment (CPE, **4**), typical to the households of Fig. 3.

[0020] Fig. 5 illustrates conceptually the relationship of the HFCN **3000** of Fig. 3 to other networks and services.

[0021] Fig. 6 illustrates an external front view of the CMTS **1000** of Fig. 1, in accordance with the present invention, including Line Cards (**100-1** through **100-8**).

[0022] Fig. 7 provides internal detail in a cut-way side view of the CMTS **1000** of Fig. 6, showing the arrangement of various Line Cards **100** and I/O Cards **200** relative to a midplane **300,** which is shown cross-section.

[0023] Fig. 8 illustrates an external rear view of the CMTS **1000** of Fig 1, in accordance with the present invention, including I/O Cards (**200-1** through **200-8**).

[0024] Figs. 9A and 9B show different views of one of the I/O Cards **200** of Fig. 8. Fig. 9A is a side view that illustrates the PCB form factor. Fig. 9B is a rear view that illustrates the connectors for various cable attachments.

[0025] Fig. 10 illustrates an internal top view of the CMTS **1000** of Fig. 6 showing card arrangement and example coaxial-cable connections.

[0026] Fig. 11 is a more detailed planar view of the midplane **300**, previously shown in cross-section in Fig. 7.

[0027] Fig. 12 provides detail of the cross-section through the J5-P5-RJ5 connectors (**155**, **355**, and **255**, respectively) of Fig. 7.

[0028] Fig. 13 illustrates the pin array of the male P5 connector **355** of Fig. 7 and its grounded shroud, each pin having annotated row and column Ids.

[0029] Figs. 14A and 14B provide detail of the female J5 connector **155**. Fig. 14A is a map showing functional assignments for each receptacle of the J5 connector, while Fig. 14B provides a legend for the different ground types represented in the map of Fig. 14A.

[0030] Fig. 15 provides an abstract perspective view, for a subset of nine connector pin-positions, of the mating of the P5 and J5 connectors of Figs. 13 and 14A. In accordance with the present invention, the nine pins and the corresponding cylindrical receptacles, comprise a quasi-coaxial protected RF interconnect, as the eight outer pins protect the inner ninth pin (at B-21).

[0031] Fig. 16 illustrates how the Line Cards **100**, I/O Cards **200**, and Midplane **300** of Fig. 1 can be configured to use the Nth Line Card as a Designated Backup (DB).

[0032] Fig. 17 provides detail of the backup bus network **17**, which couples the I/O Cards 200 of Fig. 16.

[0033] Fig. 18 illustrates a first embodiment of the Line Card 100 of Fig. 1, showing lands for the IF-to-RF module of Fig. 19.

[0034] Figs. 19A and 19B illustrate a bottom view (Fig. 19A) and a cut-away side view (Fig. 19B) of an IF-to-RF module **110** that is mountable on the Line Card **100** of Fig. 18. Fig. 19B includes the connectors **1913**, which mate with the connectors **1813** of Fig. 18.

[0035] Figs. 20A and 20B illustrate cut-away rear views of the Line Card **100** of Fig. 18. Fig. 20(A) shows the Line Card **100** without a IF-to-RF module. Fig. 20(B) shows the Line Card with the IF-to-RF module **110** of Fig 19 attached.

[0036] Fig. 21 illustrates an alternate embodiment to that of Figs. 18 through 20, wherein an IF-to-RF module **220** is coupled to the Line Card **100** of Fig. 1 using cables. Fig. 22 illustrates steps in an illustrative procedure **2200** for servicing a Line Card **100** in the CMTS **1000** of Fig 16, without recabling, and in accordance with the invention.

DETAILED DESCRIPTION

[0037] Those skilled in the art will understand that with appropriate adaptations the CMTS **1000**, in accordance with the present invention, may be deployed at any of the major nodes within regional Hybrid Fiber-Coax Network HFCNs **3000**, including at either of two types of Fiber Nodes (FN1 **3400** and FN2 **3500**), or within the Fiber Node Hubs FNH **3300**, the Primary Head End **3100**, or the Secondary Head End **3200**. The FN2s are more widely known as mini-FNs or mFNs. Compared to the larger FN1 type fiber nodes, FN2 type fiber nodes are located closer to a smaller number of subscribers, and provide a fiber overlay onto an otherwise conventional coaxial-cable distribution network. Fiber Nodes incorporating the CMTS **1000** are herein referred to as enhanced Fiber Nodes (eFNs), as exemplified by the eFN **5000** of Fig. 1(A). Additional illustrative detail of various aspects of the eFN and its CMTS is available in the following applications (previously incorporated by reference, above): "ENHANCED FIBER NODES WITH CMTS CAPABILITY," "TRANSCEIVER CHANNEL BANK WITH

REDUCED CONNECTOR DENSITY," and "MULTIPLE INPUT, MULTIPLE OUTPUT CHANNEL, DIGITAL RECEIVER TUNER."

[0038] For the purpose of this application, from the perspective of the CMTS **1000**, system applications are referred to as last-mile embodiments for those applications wherein the downstream side of the CMTS **1000** is coupled primarily to a subscriber sub-net. This corresponds typically to placement of the CMTS **1000** at an FN1 or FN2. System applications are referred to as intermediate-node embodiments for those applications wherein the downstream side of the CMTS **1000** is coupled primarily to a sub-net of FNs. System applications are referred to as Head End embodiments for those applications wherein the CMTS **1000** is located at a primary or secondary Head End. The CMTS **1000** also facilitates the splitting of system-level CMTS functionality across multiple levels of the HFCN hierarchy. E.g., CMTS functions in general, and CMTS **1000** more particularly, may exist both at the head-end and within fiber nodes. Thus hybrid system applications of CMTS **1000** are possible and likely.

[0039] In accordance with the present invention, the CMTS **1000** offers the opportunity to use packet data transmissions within the portion of the HFCN that is upstream of the CMTS **1000** to carry significant portions of the upstream and downstream DOCSIS and non-broadcast services traffic. This reduces the number and length of analog RF paths required in the HFCN, and hence can dramatically reduce the infrastructure costs per cable modem.

[0040] The role of Fiber Nodes within a last-mile embodiment will now be examined in conjunction with Fig. 3. Either type of fiber node (FN1 or FN2) may be enhanced with a CMTS to serve as the interface between the coaxial network that covers the "last mile" to subscribers' cable modems, and a set of services provided over a mixed network of coax, analog optical fiber and fiber carrying packet traffic.

[0041] The Customer Premises Equipment (CPE) at each subscriber residence **4** is illustrated in Fig. 4, which shows how network services pass information to and from cable modems, telephone modems, and TV set top boxes. The eFN couples the CPE to upstream services, such as shown in Fig. 5, connecting subscribers through the HFCN **3000** to a variety of Wide Area Network (WAN) services (e.g. Internet Service Providers, VoiceOverIP Service Providers, Application Service Providers) as well as information from Video Servers and the Public Switched Telephone Network (PSTN).

CMTS Functional Overview

[0042] The CMTS **1000** of Fig. 1(A) has data interactions with a variety of potential sources and destinations, including traffic with network nodes upstream of the CMTS (toward the head end), traffic with network nodes downstream of the CMTS (toward the subscriber), and streaming video from local video servers. The CMTS preferably communicates with the nodes upstream in the network via redundant fiber-based packet links **1035** and **1036** using a protocol such as Gigabit Ethernet. The CMTS communicates with the nodes downstream in the network via DOCSIS compatible RF channels carried on upstream RF transmission paths (collectively, **1080**) and downstream RF transmission paths (collectively, **1070**). The CMTS also optionally inserts MPEG2-TS video **1050** from video servers VSRVR **5200** (local to the FN where the CMTS resides) into the RF spectrum provided to nodes downstream.

[0043] In the illustrative embodiment of Fig. 1(A), an electrical RF interface is used to interface with the network downstream of the CMTS. Depending on the type of system application, and hence the placement of the CMTS within the overall network, the CSF function **5400** will include an optical interface and the appropriate converters, as required. Corresponding to the all-electrical CSF **5400-E** of Fig. 2(A), the CSF output

1060 is used when the interface to downstream is electrical, such as is typically the case in last-mile embodiments. Corresponding to the hybrid electrical-optical CSF **5400-O** of Fig. 2(B), the CSF fiber output **1065** is used when the interface to the downstream nodes is optical, such as is preferably the case in Head End and intermediate-node embodiments.

[0044] In a last-mile embodiment, the CMTS performs processing on downstream packets and converts them to RF-modulated analog signals to present to the subscriber network, as well as converting RF upstream signals to packets for sending over an upstream packet network. With reference again to Fig. 1(A), note that all functionality is partitioned across the cPCI midplane, placing the majority of the CMTS functionality in the cards (**100-1** through **100-N**, **700** and **800**) removably affixed to the front (to the left in Fig. 1(A)) of the midplane **300**, and allowing cabling to be made to so-called transition cards removably affixed to the rear (to the right in Fig. 1(A)) of the midplane **300**.

[0045] Packet transfers with network nodes in the upstream direction are optically coupled to the CMTS via Gigabit Ethernet on fibers **1035** and **1036**. The packets are examined by a redundant switch (card RS **700** and its associated transition card RSTC **725**), and directed to the various installed Line Cards **100-1** through **100-N** via their associated I/O Cards **200-1** through **200-N**.

[0046] As detailed in the Fig. 1(B) view of the Line Card **100-N**, these packets go directly to the MAC processing block **170-N**, are then processed by the downstream digital signal processing circuitry DSDSP **160-N** to generate a predetermined number, D, of streams of digital samples, each of which are converted to analog IF signals via respective digital-to-analog converters DAC **130-N**, and then upconverted within the IF2RF module **110-N** to produce respective RF signals **175-N**. The D RF signals **175-N**

pass through the cPCI midplane **300** and the associated I/O Card **200-N.** Referring again to Fig. 1(A), under normal operation (optional redundancy circuitry 17 in its normal pass-through state) these same D RF signals emerge from the I/O Card **200-N** as downstream signals **1070-N** which are coupled to the CSF **5400-E** to be combined with downstream signals (from other Line Cards as well as analog broadcast channels coupled via transmission paths **1010** and **1025**) and propagated to subscribers via the bi-directional coaxial-cable distribution **1060**.

[0047] Upstream signals from subscribers on the bi-directional coaxial-cable distribution **1060** are split off from the downstream signals by the CSF **5400-E** and presented to the CMTS through upstream transmission lines **1080**. These pass through I/O Cards **200-1** through **200-N** through the cPCI midplane to their associated Line Cards **100-1** through **100-N**.

[0048] As shown in more detail in Fig. 1(B), each Line Card accepts a predetermined number, U, of upstream transmission lines (collectively **150**), each of which is subsequently sampled by respective ADCs **190**. In a preferred embodiment, U=4. Within the upstream digital signal processing USDSP **180**, the output stream of each of the 4 ADCs is provided to multiple separate dynamically programmable receivers. In a preferred embodiment, the number of tunable receiver channels per ADC is also 4, coincidentally. The USDPS **180** of the preferred embodiment can thus extract and process data corresponding to 4 separate RF channels per transmission line, or 16 total upstream channels per Line Card **100**. The number of Line Cards in a preferred embodiment is 8, corresponding to 128 upstream channels in a non-redundant configuration. (Redundant Line Card configurations are discussed below.)

[0049] The extracted channel data is framed and provided to MAC function **170**, where it is merged with other channel data, and formatted into packets compatible with

Ethernet transmission protocols. The packets from each Line Card **100** are subsequently directed to the upstream network via the redundant switch RS **700** and its associated transition card RSTC **725**, discussed previously.

[0050] Control and monitoring of various chassis parameters, including numerous forms of Line Card status data, is performed by the Redundant Chassis Control Module RCCM **800** and its associated transition card RCCMTC **825**.

Subsystem Partitioning

[0051] The invention improves CMTS maintainability by partitioning most processing functions onto Line Cards that do not physically connect directly to external cables. Thus, the Line Cards can be removed from the front of the chassis for servicing without disconnecting any cables. Fig. 6 shows the front of a CMTS **1000** chassis, in accordance with the invention, illustrating the direct access to the Line Cards **100-1** through **100-8** in section **20** of the front panel. Also illustrated is the front panel access to the array of power supplies in the top **30**, and the fan grills in the bottom **10** for ventilation.

[0052] The Line Cards **100** and I/O Cards **200** interface with each other through a CompactPCI (cPCI) midplane **300**, as shown in the CMTS side view in Fig. 7. CompactPCI (cPCI) is a bus structure developed by the PCI Industrial Computer Manufacturer's Group based on the desktop PCI architecture. Line Cards **100** reside in the front of the chassis (the left side of this side view) and connect to the midplane **300** through the J1 through J5 and P1 through P5 connectors. The I/O Cards **200** mount onto the rear (shown here as the right side) of the cPCI midplane through a similar connector mating of RJ1 through RJ5 to P1 through P5. (A closer, top view of the J-P-RJ connection that provides the interface between Line Cards and I/O Cards will be shown

in a later drawing, Fig. 12, as indicated.) Fig. 7 also shows the location of other essential CMTS components within the chassis **1100** – alarm displays **600**, power supplies **500**, power connectors and circuit breakers **525**, card mounting guides **1110**, **1120**, **1210** and **1220**, and fans **425** and **450**.

[0053] The Line Card **100** in an illustrative embodiment is comprised of a combination of the cPCI 6U form factor adapter card with a "CMTS PHY (Physical) Card" installed in PMC (PCI Mezzanine Card) Slot 1. The cPCI adapter card supports three PowerPC microprocessors on-board and one MPC8240 Integrated Processor for a total of 4 processors in this illustrative embodiment. Additional computing resources may be added to the Line Card with the installation of a PrPMC (Processor PMC) card in PMC Slot 2.

[0054] An I/O Card is associated with each Line Card and mounts on the rear side of the cPCI midplane, directly behind each Line Card. This enables all cable connections to be made onto the I/O Cards **200-1** through **200-8** at the rear of the CMTS, as shown in section **50** of the external rear view illustrated in Fig. 8. Also illustrated are again fan grills at the bottom **40**, power connectors in section **60**, and top fan grills in section **70**. Side and rear views of the I/O Card **200** are shown in Figs. 9A and 9B. The I/O Card provides rear-panel connectors for all traffic-oriented data entering or leaving the Line Card, including the NIC interfaces (2 Ethernet ports, **25** in Fig. 9B), IF/RF Downstream out (4 F connectors **45**), RF Upstream in (4 F connectors **35**). In a first embodiment, the I/O Card contains only interconnect and no components. In a second embodiment, the I/O Card preferably implements RF relays or switches and related interconnect to implement a backup-bus for support of N+1 redundancy switchover of the IF/RF signals to a designated backup Line Card, as discussed further below.

[0055] In other embodiments, the I/O Card incorporates various degrees of video processing circuitry, ranging from video pass-through, to heavy stream processing, to high-bandwidth video distribution. These embodiments will also include MPEG-TS (MPEG-2 Transport System) inputs using 4 DV-ASI connectors **15**, as illustrated in Fig. 9B. Some of these later embodiments make use of a modular daughter card having DVB-ASI-compatible video receiver circuitry. Features of the video receiver daughter card preferably include: Support for QAM-64 or QAM-256 signals on each of 4 independent channels, with the QAM-rate being software selectable via an I2C-compatible bus. One of the input port accepts an MPTS+ stream, composed of 4 independent MPEG2 transport stream channels, operating at either QAM-64 or QAM-256. The receiver card recovers each channel's MPEG transport bit stream and timing information. The recovered streams and timing are subsequently coupled from the I/O Card, across the midplane, and to the downstream signal processing of the associated Line Card for DOCSIS multiplexing and modulation.

[0056] Serviceability of the CMTS is similarly enhanced for the redundant Chassis Control Modules **800-1** through **800-2** (CCM or Standard cPCI CPU Card) via the presence of a transition module **825-1** through **825-2** that moves cable connections for the CCM to the rear of the CMTS. The CCM card is the controlling element of the chassis. Two such cards monitor the health and status of all modules, and manage the chassis resources. In addition, the CCM may be used to run configuration and management software. The CCM will be able to "read" the Alarms and display such information to the Alarm Card using the I2C bus. The transition module is mostly a 1-to-1 interface from the front connectors of the Chassis Control Module, and presents the mechanical interfaces in the back of the chassis. Such transition module allows cabling removal (Ethernet 10/100BaseT and RS232 used for local and remote system

management) that would exist in front of the chassis. The design philosophy is to avoid all cables in front in order to keep all cards really "hot swappable" without interference from encumbering cables.

[0057] An internal top view of the chassis is represented in Fig. 10, which illustrates the layout and presence of multiple pairs (up to 8) of Line Cards **100-1** through **100-N** and I/O Cards **200-1** through **200-N**, IF-to-RF modules **110-1** through **110-N** mounted directly onto the Line Cards and electrically connected through **115-1** through **115-N**, as well as CCM and Network Cards, and representative cable inputs (**225** is an upstream signal, **250** downstream).

RF Connector Pass-Through

[0058] A feature of the invention that facilitates the separation of the I/O Card from the Line Card in an illustrative embodiment is the unique configuration of the pins on the P5/RJ5 **355 / 255** connectors on the cPCI midplane **300**. Fig. 11 shows the layout of the cPCI midplane, with P1-P5 connectors **310, 320, 330, 340, 350** for each Line Card and I/O Card pair, 8 48-Pin Connectors and 2 Power Connectors **360**, clock and other signal connectors **370**, and fan connectors **380**. The P5 connector on the midplane carries the IF or RF signals from the Line Cards to the I/O Cards, which deliver them to "F" connectors on the back of the chassis.

[0059] A top view cross-section of J5/P5/RJ5 connection is illustrated in Fig. 12, showing the 5 columns of female receptacles on the Line Card and I/O Card J5 / RJ5 connectors **155** and **255** that connect to the male pins on the cPCI midplane's P5 connector **355**. The pin configuration of P5 and the channel arrangement is provided in Fig. 13 (note that this is not drawn to actual physical proportions).

[0060] Figs. 14A and 14B show pin assignments for the J5 connector. RF1 through RF4 correspond to four downstream IF/RF signal paths. US1 through US4 correspond to four upstream RF signal paths. As shown, the pins surrounding each RF RF signal path are connected to RF Ground, making each downstream and upstream signal path have quasi-coaxial-cable characteristics with impedance close to 75 Ohms.

[0061] Another abstract view for one of the RF signal paths is provided in Fig. 15. Here a set of 9 mated pin-receptacle interconnects are shown that collectively have protective and impedance similarities to a coaxial cable, with the center interconnect carrying the signal and the 8 surrounding interconnects providing ground and shielding. The mated J5-P5-RJ5 connector arrangement has been empirically shown to have a negligible impedance discontinuity, and to provide sufficient shielding to meet DOCSIS 2.0 specifications for channel-to-channel crosstalk under worst-case conditions.

[0062] Other pins on the J5 connector of Fig. 14A are used to provide I/O Card power (+5 and +12V), I2C data bus signals (SD) and I2C clock (SCLK). The URLYxx and DRLYxx pins are described in the next section.

<u>Failover Capability</u>

[0063] Providing generalized MxN redundancy, especially in the UHF portion of the radio frequency spectrum, is expensive. A preferred embodiment of the CMTS **1000** offers simplified 1xN redundancy, providing automatic failover protection in the case of failure (or other out of tolerance condition) of an individual Line Card. This approach has a significantly reduced cost of implementation compared to the higher redundancy approaches, while providing a high level of benefit.

[0064] As described in detail below, upon detection of a failed Line Card, software appropriately configures a Designated Backup (DB) Line Card as a temporary

replacement, and RF signals to and from the DB Line Card replace those of the failed card. More specifically, the downstream outputs and upstream inputs of the I/O Card associated with the failed Line Card are automatically uncoupled from the failed Line Card and coupled instead to the Designated Backup Line Card. RF swiches and multiplexers provide the selective coupling.

[0065] Solid-state RF switches and multiplexers are available at low cost. Suitable switches for the purposes discussed below are often employed in the cellular telephone industry for the optional provisioning of attenuation in an RF signal path. These switches have insertion losses of under 0.5dB at 1 GHz and are controllable by means of logic-level signals.

[0066] Fig. 16 illustrates a particular 1xN redundancy embodiment of the CMTS **1000**, wherein a number of switch networks **17** are deployed on each of N I/O Cards and interconnected when possible to immediately adjacent (above and below, as applicable) switch networks **17**. Cabling **2000** includes up to D downstream cables and U upstream cables associated with each of the lower N-1 Line Cards. The top Line Card **100-N**, associated with I/O Card 200-N, is a Designated Backup Line Card. In association with Line Card **100-N**'s status as the Designated Backup, the switch network **17** of I/O Card **200-N** is specially connected to itself via external cabling **210** and **220**.

[0067] In Fig. 16 a distributed "backup-bus" is formed by the switch network 17 of each I/O Card together with the interconnect associated with the "vertical" downstream and upstream signals between the I/O Cards. Where adjacent I/O Cards exist, there is an "upper card" and "lower card" relationship between any pair of I/O Cards. For each such I/O Card pair, the backup-bus downstream path **1735** of the upper card is coupled to the backup-bus downstream path **1730** of the lower card, and the backup-bus upstream path **1740** of the lower card is coupled to the backup-bus upstream

path **1745** of the upper card. (The foregoing uses the up and down sense implicit in the card arrangement shown in Fig. 16, which is an obviously arbitrary directional orientation used as a convenience for purposes of this description.)

[0068] The functionality of switch network **17** may be understood at a number of different levels of abstraction, corresponding to the various dashed boxes of Fig. 17. Those skilled in the art will understand that the functionality provided at a particular level of abstraction can be implemented in a variety of ways, and the lower levels of abstraction provided in Fig. 17 are merely an illustrative implementation. As illustrated in Figs. 16 and 17, there are D physical downstream RF interconnects in each downstream path and U physical downstream RF interconnects in each upstream path. In a preferred embodiment, D=U=4. The interconnects are also generally protected in the preferred embodiment, being controlled impedance paths and incorporating some degree of shielding to meet RF cross-talk, emissions, and susceptibility requirements. As discussed elsewhere, up to 4 upstream channels may be processed per physical upstream interconnect.

[0069] At the top level, the switch network **17** operates in a pass-through mode in normal operation, wherein the Line Card downstream path is coupled to output downstream path **1070**, input upstream path **1080** is coupled to Line Card upstream path **150**, backup-bus downstream path **1730** is coupled to backup-bus downstream path **1735**, and backup-bus upstream path **1745** is coupled to backup-bus upstream path **1740**.

[0070] The switch network **17** can be reconfigured to a backup mode (also referred to as the redundant configuration) whenever the associated Line Card fails, wherein backup downstream path **1730** is coupled to output downstream path **1070**, input upstream path 1080 is coupled to backup upstream path **1740**, and the Line Card downstream path **175** and Line Card upstream path **150** are isolated.

[0071] At the lower levels, switch network **17** is composed of separate switching blocks **1720** and **1720**, for the downstream and upstream paths, respectively. These blocks include respective switch modules **1715** and **1725** and associated wiring. The xD (times D) and xU (times U) notation indicates that these blocks and modules are actually replicated D and U times, respectively. This is consistent with the "slash D" and "slash U" notation used for the downstream and upstream paths, respectively. Those skilled in the art will understand that this permits each of these blocks and modules to be abstractly represented in Fig. 17 using a single instance of each to minimize visual clutter and facilitate illustration of the concept.

[0072] The switch modules **1715** and **1725** in Fig. 17 are illustrated with switch positions corresponding to the pass-through mode of operation discussed above. The backup mode is achieved by directing all of the switches to the switch-state opposite that shown. Each of the switch modules **1715** and **1725** is illustrated using two single-pole-double-throw (SPDT) RF switches with logic-level control inputs (not shown, but described next).

[0073] The URLYxx and DRLYxx pins (where u and d range from 1 to 4, and s is 0 or 1) of the J5 connector of Fig. 14A correspond to the logic-level switch controls signals. In this illustrative embodiment there are 8 DRLYxx (Downstream ReLaY xx) control signals, where xx is of the form *d:s*, with *d* ranging from 1 to 4, and *s* ranging from 0 to 1. The *d* identifier specifies the particular downstream path of the D paths and the *s* identifier specifies the particular switch of the upper and lower switches of the switch module **1715**. Similarly, there are 8 URLYxx (Upstream ReLaY xx) control signals, where xx is of the form *u:s*, with *u* ranging from 1 to 4, and *s* ranging from 0 to 1. The *u* identifier specifies the particular upstream path of the U paths and the *s*

identifier specifies the particular switch of the upper and lower switches of the switch module **1725**.

[0074] Providing the 4 control signal pairs for upstream control and the 4 pairs for downstream control provides maximum flexibility, but this high degree of control is beyond that required for switching merely between pass-through mode and backup mode. Those skilled in the art will recognize that a wide range of control signal flexibility is possible. Other implementations may well reduce the number of control signals. Depending upon the true/false logic defined for the switch module control inputs, a minimalist implementation could use only one control input, or one pair of complementary control inputs.

[0075] Those skilled in the art will further readily appreciate that other routing topologies, using other combinations of various switch types, are readily derived while providing equivalent functionality at the higher levels of abstraction. Furthermore, all of these switches may be implemented at the physical level in a variety of ways.

[0076] As a specific example of an alternate implementation (or equally as an alternate perspective on the same functionality), each of the switching blocks **1710** and **1720** can be implemented as a combination multiplex and switch function. Specifically, switch block **1710** can be viewed as implementing a multiplexer having paths **175** and **1730** as inputs and path **1070** as an output. An additional switch provides the selective coupling of the path **1730** to path **1735**. Similarly, switch block **1720** can be viewed as a multiplexer having paths **1080** and **1745** as inputs and path **1740** as an output. An additional switch provides the selective coupling of the path **1080** to path **150**.

[0077] The interconnect topology provided by **210** and **220** in Fig. 16 allows a common I/O Card to be used in all I/O Card slots of the CMTS. Commonality of parts has well known serviceability and economic benefits. Those skilled in the art will

recognize that for the 1xN redundancy configuration taught in this section, no switch network is required for the I/O Card associated with the Designated Backup. That is, with reference to Fig. 17, it would be sufficient to directly couple backup downstream signals **175** as signals **1735** and likewise couple signals **1745** as backup upstream signals **150**. Such an approach would also eliminate the external cabling.

[0078] Those skilled in the art will also recognize that if redundancy is not needed, the switch network **17** may be done away with entirely, replaced by pass-through interconnect, such that Line Card downstream path **175** is always coupled to output downstream path **1070** and likewise input upstream path **1080** is always coupled to Line Card upstream path **150**. In such a non-redundant embodiment, the backup-bus card-to-card interconnect between I/O Cards would not be provided.

[0079] A number of options also exist for the card-to-card interconnects comprising the backup-bus. In a first embodiment they are controlled-impedance traces on the midplane. In a second embodiment, miniature cables and surface-mount connectors are used, with multiple "flying leads" between the I/O Cards. In variations of the second embodiment, miniature multi-pin coaxial connectors and/or multi-coaxial "flat cables" may be employed, to reduce the number of individual connectors and flying leads.

[0080] The difficulties of dealing with the card-to-card interconnects is offset by the very attractive fact that all backup services are provided within the envelope of the one card cage; no additional external equipment or cables are required. Various degrees of redundancy can be offered simply by choosing how many Line Cards to group, with one of the group being the "Designated Backup".

[0081] When the Chassis Control Module (CCM) determines that a Line Card is not operating properly, it coordinates the switchover to the Backup Line Card. In an

illustrative embodiment, an "RF present" signal (or the logical compliment, RF absent) may be derived from each downstream signal line, and made available for reading via an I2C-compatible interface. This need not be an accurate measure of RF power, but merely a "yes or no" indication of the presence of the RF signal. In a preferred embodiment, the CCM monitors several status data concerning an operational Line Card, including IF or RF output levels, operational status of all processors, ASICs, IF-to-RF upconvertors, 100BaseT interfaces, the serial RS-232 interface, and any alarm events related to any operational parameter being outside of limits or any fault condition.

[0082] The Chassis Control Module (CCM) handles control of the switch network **17**. As indicated previously, there is no need to switch each RF path independently. In the illustrative embodiment, all eight paths are switched simultaneously between pass-through mode and backup mode, using a single command. The commands are sent along one of two midplane-carried I2C buses (one for each half of the total backplane width). The I2C address of each switch controller is determined solely by the physical position of the card within each half of the card cage. No jumpers or switches are used for this purpose; plugging an I/O Card into a specific position on the midplane is sufficient.

[0083] The I/O Card supports operation of the backup bus whether or not the Line Card is in place. Accordingly, the I2C switch drivers derive power directly from the midplane, and not the "frontside" Line Card. The default power-on state of the switches places the switch network **17** in the pass-through mode.

[0084] To enable proper activation of a Backup Line Card, the Chassis Control Module stores the state information of all Line Cards and Network Cards in the chassis. The maximum amount of data is estimated to be 200 megabytes. Upon the need for redundant switchover of a Line Card, the chassis control module transfers the latest state

information of the failed card to the Designated Line Card before actually activating the backup card for primary operation.

Line Card Modularity

[0085] In the preferred embodiment of this invention the Line Cards are further partitioned into easily replaceable sections, including a detachable module for optional IF-to-RF functionality and a detachable daughter card for the signal processing functions, to make a single module for easy hot swap and maintenance. This configuration is depicted in Fig. 18. The IF2RF module (the large dotted-line rectangle on the left) receives analog IF downstream signals **125** through complementary pairs of push-on-mating (including slide-on and snap-on, and preferably self-aligning) coaxial connectors, one set **1813** on the Line Card and one set **1913** on the IF-to-RF module. These signals **125** are created by digitally processing (DSDSP **160**) information coming from packet OADM interfaces or Video Server inputs **1050** and then converting those signals to IF (D/A convertors **130**). The IF2RF module then acts as upconvertor, preparing that IF signal for delivery to the subscriber line **175**. Fig. 18 also shows the processing of the upstream signal (which does not use the IF2RF module). The upstream RF signal is passed from the I/O Card to the Line Card through its J5 connector, becoming signal **150**. This signal is digitized by the A/D convertor **190** and then digitally processed (USDSP **180**) and run through various MAC functions before being routed as packets upstream **726**. Item **1812** depicts the I2C / Power Connectors for the card.

[0086] Layout of the IF-to-RF module **110** is shown in Fig. 19A, indicating multiple IF to RF convertors **1911-1** through **1911-N** on a single module, their various IF and RF interface connections, and the I2C and Power Connectors **1912**. The side view shown in Fig. 19B illustrates the connectors **1913** that connect to mates on the Line Card.

In the preferred embodiment, this is implemented using complementary pairs of push-on-mating (including slide-on and snap-on, and preferably self-aligning) coaxial-connectors. Figs. 20A and 20B demonstrate different stages of assembly. Fig. 20A shows a Line Card with no IF-to-RF module, while Fig. 20B shows an IF-to-RF module mounted on the Line Card of Fig. 20A. The IF-to-RF module is separately physically retained. An alternate embodiment of the IF-to-RF module, shown in Fig. 21, provides electrical connection through cables. This latter embodiment reduces component costs at the expense of increased time and labor to accomplish the interconnection of the IF-to-RF module with the Line Card.

<u>Dynamic Channel Assignment</u>

[0087] To minimize the need for technician-performed channel adjustments, the invention incorporates circuitry that enables the channel assignments to be programmed dynamically, based on internal computations or instructions from the head-end. Thus the channels assigned to an individual IF-to-RF upconverter and its associated upstream digital demodulator can be altered dynamically for noise abatement or other reasons.

<u>Line Card Servicing</u>

[0088] The course of events associated with failure of a Line Card in the present invention is described by Method **2200**, which is illustrated in Fig. 22. The beginning Step **2210** is established by installing and configuring the Line and I/O Cards in the chassis and connecting all associated cables to their appropriate places on the I/O Cards. In Step **2220**, chassis monitoring and control circuitry continuously records the state information of all Line Cards. In the event of a Line Card failure (detected within the decision box of Step **2230**), this state information is used in Step **2240** to setup and

configure the Designated Backup Line Card. Once the backup is configured, the control circuitry switches the affected datastreams over to the backup card and sets appropriate alarms in Step **2250**. Servicing of the CMTS then begins in Step **2260** with removal and replacement of the affected card. Once the new card is installed, the control circuitry then configures the state data on the new Line Card in Step **2270**, and switches the datastreams from the Designated Backup card back to the new Line Card in Step **2280**. At no point subsequent to the initial installation is it necessary to manipulate any of the cables.

CONCLUSION

[0089] Although the present invention has been described using particular illustrative embodiments, it will be understood that many variations in construction, arrangement and use are possible consistent with the teachings and within the scope of the invention. For example, interconnect and function-unit bit-widths, clock speeds, and the type of technology used may generally be varied in each component block of the invention. Also, unless specifically stated to the contrary, the value ranges specified, the maximum and minimum values used, or other particular specifications, are merely those of the illustrative or preferred embodiments, can be expected to track improvements and changes in implementation technology, and should not be construed as limitations of the invention. Functionally equivalent techniques known to those skilled in the art may be employed instead of those illustrated to implement various components or sub-systems. It is also understood that many design functional aspects may be carried out in either hardware (i.e., generally dedicated circuitry) or software (i.e., via some manner of programmed controller or processor), as a function of implementation dependent design

constraints and the technology trends of faster processing (which facilitates migration of functions previously in hardware into software) and higher integration density (which facilitates migration of functions previously in software into hardware).

[0090] Specific variations within the scope of the invention include, but are not limited to: the use of means other than CompactPCI midplanes to provide Line Card and I/O Card separation, including the use of self-adjusting push-on-mating connectors where size and cost are not an object; the use of other types of connectors to provide easy mounting and disassembly of the IF-to-RF module onto and off of the Line Card; implementations carrying different numbers of upstream and downstream signals on a given Line Card; and separation of Line Card and I/O Card functionality for Line Cards that do not provide the ability to dynamically assign and adjust receiver channels. In addition, the primary embodiment illustrated has been the application of the invention in a last-mile embodiment. It is recognized that the invention is similarly applicable within intermediate embodiments or head end embodiments.

[0091] All such variations in design comprise insubstantial changes over the teachings conveyed by the illustrative embodiments. The names given to interconnect and logic are illustrative, and should not be construed as limiting the invention. It is also understood that the invention has broad applicability to other telecommunications applications that process and pass RF signals, for enhancing their Reliability, Availability and Serviceability (RAS), and is not limited to the particular application or industry of the illustrated embodiments. The present invention is thus to be construed as including all possible modifications and variations encompassed within the scope of the appended claims.